Evaluación de Riesgos Naturales
- América Latina -
Consultores en Riesgos y Desastres

ERN

CAPRA

CENTRAL AMERICA PROBABILISTIC RISK ASSESSMENT

EVALUACIÓN PROBABILISTA DE RIESGOS EN CENTRO AMÉRICA

BELIZE

TASK IV

HAZARD, RISK MAPS AND RISK MANAGEMENT APPLICATIONS

TECHNICAL REPORT SUBTASK 4.2D

COST-BENEFIT ANALYSIS OF HURRICANE RISK MITIGATION FOR SCHOOLS AT NATIONAL LEVEL

CEPREDENAC

Estrategia Internacional para la Reducción de Desastres EIRD

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LIMITATIONS AND RESTRICTIONS

This application is illustrative, and has limitations and restrictions due to the level of resolution of available information. The final user should be aware of this, so that he will be able to make appropriate and consistent use of the results obtained, taking account of the type of analysis made, the type and quality of data used, the level of resolution and precision, and the interpretation made. Therefore, the following should be noted:

- Models used in the analysis contain simplifications and suppositions in order to facilitate the calculation which the user of which the user should be aware. They are described in detail in the related technical reports.
- The analyses have been developed with the best information available, within limitations of reliability and currency. It is possible that better and more complete information exists, but that we did not have access to it.
- The information used and the results of the analysis of hazards, exposure and risk are associated with a level of resolution, depending on the unit of analysis used, and this is explained in the descriptive document of the example.
- The use which the final user makes of the information does not in any way involve liability on the part of the authors of the study is made, who present this example as a something which could be feasible, if reliable information with appropriate degrees of precision were made available.
- It is the user´s responsibility to understand the type of model used and its limitations, resolution and the quality of data, limitations and assumptions for analysis, and the interpretation made in order to give these results appropriate and consistent use.
- Neither those who developed the software nor those who promoted and financed the project, nor the contractors or subcontractors who took part in applications or examples of the use of the models, assume any liability for the use which the user gives to the results presented here, and therefore they are free of all liability for loss, damage, or effects which may be derived from the usual interpretation of these demonstrators examples.

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1 Introduction

In practice, the most effective way of reducing risk to infrastructure is by retrofitting it or to recondition its structural and non-structural elements. This process requires quite a high level of investment, and the purpose is to reduce the vulnerability of those elements and so therefore, the level of risk. The reduction of vulnerability and risk is then reflected in a reduced level of expected losses in future events. The reduction corresponds not only to direct physical losses, but also to the loss of contents of the components affected, losses due to interruption of operation, indirect impact such as the effect on persons (deaths and injuries), and in considerations associated with reduction or interruption of functionality; and aspects related to indirect social effects, which are in general very difficult to quantify, and not often taken into account.

This proposal entails the possibility of making benefit-cost evaluations for different alternatives in retro fitment or reconditioning, in order to acquire clear criteria to define the optimum option for intervention and to promote and propose priorities among a series of alternatives. These alternatives must be technically viable, in the context of limited availability of resources. In this relationship, the benefit corresponds to the savings on expected future losses (including direct and indirect losses, interruption of activity of social, environmental and functional activities, and in general all losses associated with adverse effects of the component), while the cost corresponds to the value of each of the various alternatives for intervention.

The evaluation of the expected future losses is based on the occurrence of events with different intensities. Due to the uncertainty associated with in the occurrence of future events, it is used a simulation of processes which follows the relations of historical recurrence, or to the evaluation of a probabilistic model, also calibrated with a historical in occurrence of events. Therefore, for each simulation of events, there are some future potential losses, brought to present value for comparison purposes (in the same, present time), with the initial investment as a consequence of the intervention proposed.

In the context of a probabilistic assessment, the distribution of probabilities of the cost - benefit ratio must be determined. In this case, the net present value of savings of expected future losses is used (considering both the condition of intervention and that of no-intervention), and this value is then compared to the cost of the same intervention (retrofitting of the structure), in current conditions. The method is also applicable to a design situation, in which the intention is to evaluate different alternatives at design level.

The objective of the simulation presented below consists of evaluating the potential risk to several school buildings in Belize in the face of future hurricane events, expressed in terms of an average annual economic loss, in order to conduct a cost-benefit analysis, in which the process simulation of expected future losses and their reduction can be observed in the light of alternative interventions to improve the performance of buildings. This analysis is made in probabilistic terms, and is seen from the point of view of the recurrence model for events, based on past hurricanes.

The analyses presented here are an illustration of the methods and capacities of CAPRA tools. In general, they are based on information taken from other, similar analyses, attempting to adapt information to local conditions. The method proposed must serve as the basis for updating, purging and refining information in the model by local working groups, with the participation of public servants, who should form research groups with specialists in the subject.

2 Methodology for analysis

The analysis of risk based on cost-benefit ratios has two great advantages:

- It offers direct information which will enable different alternatives for mitigation reduction of risk to be assessed, since in each case there can be an evaluation of social socio-economic impact of each alternative.

- It represents technically valid and clear criteria to establish priorities for intervention in a number of components, or to define works of intervention to be performed, always in terms of maximizing the benefit-cost ratio. This will make it possible for programs of investment in mitigation and in the reduction of risk to be rationally constructed.

In these types of analysis, the benefits are related to future savings which can be achieved in terms of direct losses, loss of contents and indirect expected losses, and a potential reduction in direct social effects, and the loss of functionality which may arise, and possible future maintenance savings. For this, there must be a relatively reliable estimate of the investment required for each of the alternatives of mitigation, including direct costs, indirect costs, administration, financial costs and eventual future maintenance costs over the period of time selected for the analysis, which is normally of a period of several years. A reliable relationship must also be established between possible interventions to be performed and the potential reduction in vulnerability or hazard achieved. The economic benefits which would be generated in the future must be brought back to present value, so that a suitable economic comparison can be made, applying appropriate discount rate.

Figure 2-1 presents the scheme of a typical benefit-cost analysis, in which, for appropriate comparison, future costs and benefits generated by the implementation of structural measures must be brought to present value, and compared to the initial investment required.

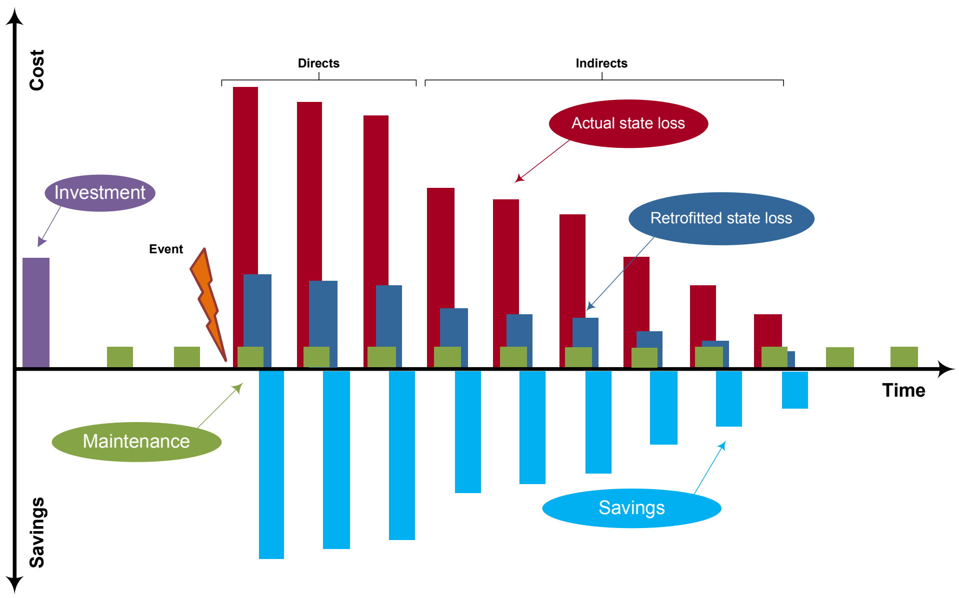

Figure 2-1 Analysis of net present value of costs, benefits and initial investments in structural measures for mitigation

The cost-benefit ratio, $\boldsymbol{Q}$, is defined as the relationship between losses saved due to the implementation of structural intervention programs, and the initial cost of the intervention projected. Hence, the benefit-cost ratio can be proposed in the following way:

$$\boldsymbol{Q} = \frac{\boldsymbol{L_U} - \boldsymbol{L_R}}{\boldsymbol{R}} \qquad \textbf{(Eq. 1)}$$

Where $\boldsymbol{L_U}$ is the present value of the future losses in a non-intervened state, and $\boldsymbol{L_R}$ is the present value of future losses in the intervened state, and these correspond to random variables with a known probability distribution, and can therefore be calculated. And $\boldsymbol{R}$ corresponds to the cost or value of the investment due to the execution of the intervention program.

The $\boldsymbol{L_U}$ and $\boldsymbol{L_R}$ values can be calculated as follows:

$$L = \sum_{i=1}^{\infty} \beta_i e^{-\gamma t_i} \qquad \textbf{(Eq. 2)}$$

where $\boldsymbol{\beta_i}$ corresponds to the value of the loss due to an event i in a time t, and γ corresponds to the discount rate. According to (Ordaz, 2009), the calculation of the two statistical moments of the random variable. L is obtained as follows:

$$E(L) = \frac{E(\beta_A)}{\gamma} \qquad \textbf{(Eq. 3)}$$

$$VAR(L) = \frac{VAR(\beta_A)}{2\gamma} \quad \textbf{(Eq. 4)}$$

According to (Ordaz; 2009) net present value of future losses can be represented through a Gamma distribution with current parameters given as follows:

$$p\ (L) = \frac{L^{r-1}\exp(-\lambda L)\lambda^r}{\Gamma(r)} \quad \textbf{(Eq. 5)}$$

$$E(L) = \frac{r}{\lambda} = \varepsilon \quad \textbf{(Eq. 6)}$$

$$C(L) = \frac{1}{\sqrt{r}} = C \quad \textbf{(Eq. 7)}$$

With this, our interest is aroused in an evaluation of the expected value of the cost-benefit ratio ***E(Q),*** and the probability that this ratio will be positive ***PrQ>1).***

$$E(Q) = \frac{E(L_U) - E(L_R)}{R} \quad \textbf{(Eq. 8)}$$

Where $\boldsymbol{E(L_U)}$ and $\boldsymbol{E(L_R)}$ are the expected net present values of future losses for the current state, and the intervened state, respectively.

The probability of obtaining a positive cost-benefit ratio can be calculated by the following expression:

$$\Pr(L_U - L_R > R) = 1 - \int_0^\infty Gac(R + y; r_U, \lambda_U) p_R(y) dy \quad \textbf{(Eq. 9)}$$

Where *Gac(x;r,γ)* is the cumulative Gamma function, given by

$$Gac(x; r, \lambda) = \int_0^x \frac{y^{r-1}\exp(-\lambda y)\lambda^r}{\Gamma(r)} dy \quad \textbf{(Eq. 10)}$$

3 Exposed elements

The information on elements exposed to natural events consists of an inventory of buildings which may be affected by them. This is expressed in terms of assets and of people. This is an essential component in the evaluation of risk and the degree of certainty of results depends on levels of resolution and detail. Where there is no detailed information, as here, estimates of the inventory must be made to establish the exposed assets, with broad-brush indicators, and expert opinions. This would be known as a proxy exposure model.

Another objective of the model for exposure with regard to schools, nationwide (proxy), is also to create an appropriate distribution for the inventory in terms of national geographical units or political divisions. The basis of information for the estimates of exposure is in general taken from economic, human and welfare development indicators and construction prices. The proxy exposure model requires the following points to be defined:

(a) Geographical and political division: the model is presented with a categorization of sub-national and municipal units.

(b) In order to characterize the urban areas, an evaluation is made at the same level, in homogeneous zones and in terms of infrastructure characteristics, population density, economic activity, and socioeconomic conditions, amongst other matters.

More detailed geographical areas may be used if required for the analysis. For example, in cities, suburbs may be included depending on the information available.

In general, it is important to note that usually, for the representation of exposure, it is not possible to obtain information on an element-by-element basis (for example, property-by-property), since there is no available property record available. In most cases, a proxy is developed by using indirect variables, and a series of correlations.

3.1.1 *Estimation of constructed area of educational buildings*

The most reliable parameters for this analysis are the official population statistics reported for each sub-national political and administrative unit, and the estimated number of pupils published by the Ministry of Education. For the calculation of the constructed area of schools, we assume an average construction area per student or pupil in the school; and this value depends on the level of complexity of each municipality, and whether the school is public or private. Table 5-1 shows the urban population range which is used for each level of complexity.

$$Aedu(m^2) = CE[Est] \times ME\left[m^2/_{Est}\right] \times PEP[\%] \qquad \textbf{(Eq. 11)}$$

A*edu:* constructed educational area
CE: number of students of each administrative area.

ME: average constructed area per student index. Depends on the complexity level of the administrative level.
PEP: percentage of students on public institutions for each complexity level (see Table 3-1). For private education the PEP value is replaced for (1-PEP).

Table 3-1 Population and percentages of public education by levels of complexity

Complexity level	Population in urban areas	Public education (%)
High = 1	> 100,000	50
Medium = 2	20,000 a 100,000	80
Low = 3	< 20,000	100

As a result of a detailed review of the available database for public buildings in Bogota, which were classified for the evaluation of vulnerability and mitigation of seismic risk by the Bogota Education Secretary (2004), it was found that the constructed area per student in most schools contained in the based database is between 0.3 and 2.1 square meters (see Figure 3-1). Furthermore, the manual for the evaluation of socio-economic and environmental impact of disasters, according to get ECLAC (2003), suggests different values for the construction area per student. These values are presented in Table 3-2 and Table 3-3. For Belize, for example, the constructed area per student is close to 1.45 square meters.

On the other hand, the UNESCO Education Develop Indicator – EDI - (2010) classifies countries in the region in terms of achievement of educational targets (see Figure 3-2). Therefore, using construction area indicators per student as mentioned above, and the EDI classification, it will be possible to estimate this indicator for Belize, on the assumption that the greater the EDI, the greater the educational coverage in area. The results of the ratio between EDI and constructed area per student are shown in Table 3-4 and Figure 3-3.

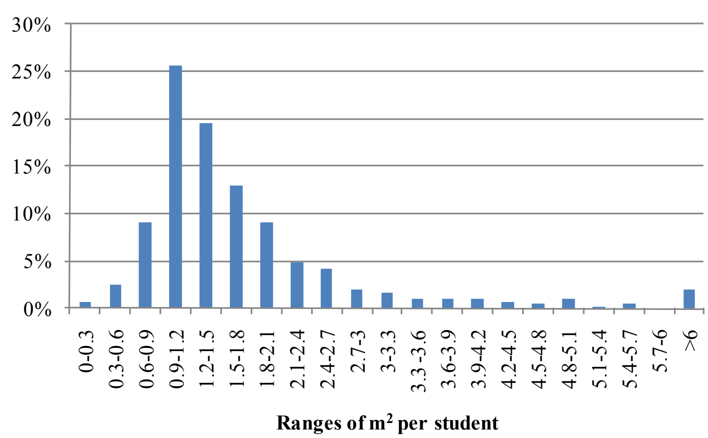

Figure 3-1
Relative frequencies of ranges of constructed area per student (Bogota)
Source: Bogota Education Secretary

Table 3-2
Constructed area per student in some Latin American countries
Source, ECLAC

Classrooms for Basic and Secondary Education. (m^2 per pupil)		
Total constructed area	Argentina	Paraguay
	6	1.2
Classroom area	Uruguay and Peru	Guyana and Haiti
	1.5	0.9

Table 3-3
Constructed area in educational services in some Latin American countries
Source: ECLAC

Other educational services(m^2 per pupil)		
Admin. buildings	Argentina	Bolivia
	0.85	0.05
Laboratories	Ecuador	Dominican Rep.
	3.8	1.2
Technical workshops	Ecuador	Uruguay
	5	1.2
Art studios	Paraguay	Uruguay and Peru
	6	1.5
Industrial workshops	Guyana	Guatemala
	9	4.5
Libraries	Brazil	Bolivia
	4.32	0.15
Music rooms	Paraguay	Argentina
	2.7	1.2

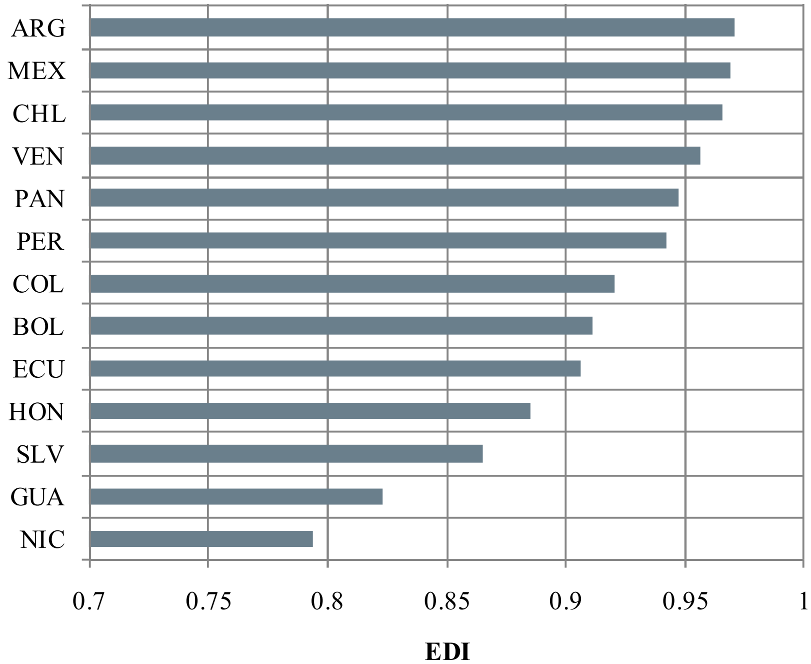

Figure 3-2
Classification of Latin American countries as a function of educational development
Source: UNESCO

Table 3-4
Constructed area per student for countries in the region, classified by levels of complexity

Country	EDI	m^2 per pupil (estimated)	Complexity level		
			Low	Medium	High
NIC	0.794	0.78	0.78	0.93	1.09
GUA	0.823	0.84	0.84	1.01	1.18
SLV	0.865	0.91	0.91	1.10	1.28
HON	0.885	1.05	1.05	1.26	1.48
ECU	0.906	1.42	1.42	1.70	1.99
BLZ	0.907	1.45	1.35	1.62	1.88
BOL	0.911	1.50	1.50	1.79	2.09
COL	0.92	1.79	1.79	2.15	2.51
PER	0.942	3.02	2.42	3.02	3.63
PAN	0.947	3.31	2.65	3.31	3.97
VEN	0.956	3.77	3.02	3.77	4.53
CHL	0.966	4.25	3.40	4.25	5.10
MEX	0.969	4.40	3.52	4.40	5.28
ARG	0.971	4.52	3.61	4.52	5.42

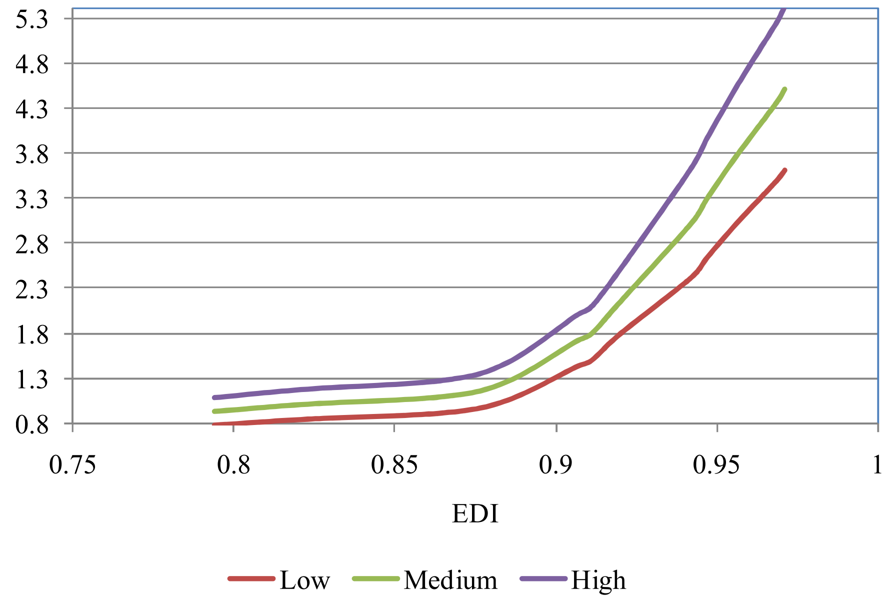

Figure 3-3
Constructed area per student and by values of EDI

3.1.2 *Cost of buildings and exposed values*

In order to make an appropriate identification of the cost of buildings, we obtained prices per square meter from information available in the statistical office for each country. Since this information was not available in some cases, it was necessary to establish some relationship between them. Therefore, the exposed value per student was related to the minimum salary, and GDP per capita. Therefore, the square meter costs were adjusted in accordance with those parameters, as shown in Figure 3-4

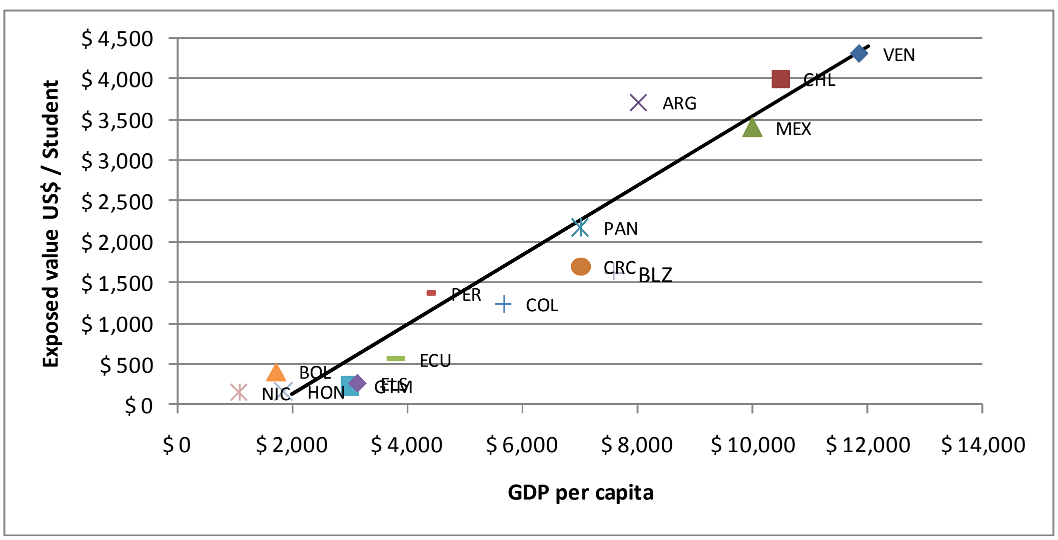

Figure 3-4
Relationship between GDP per capita and exposed value per student

The results of the estimate for constructed areas of schools in Belize are shown in Figure 3-5

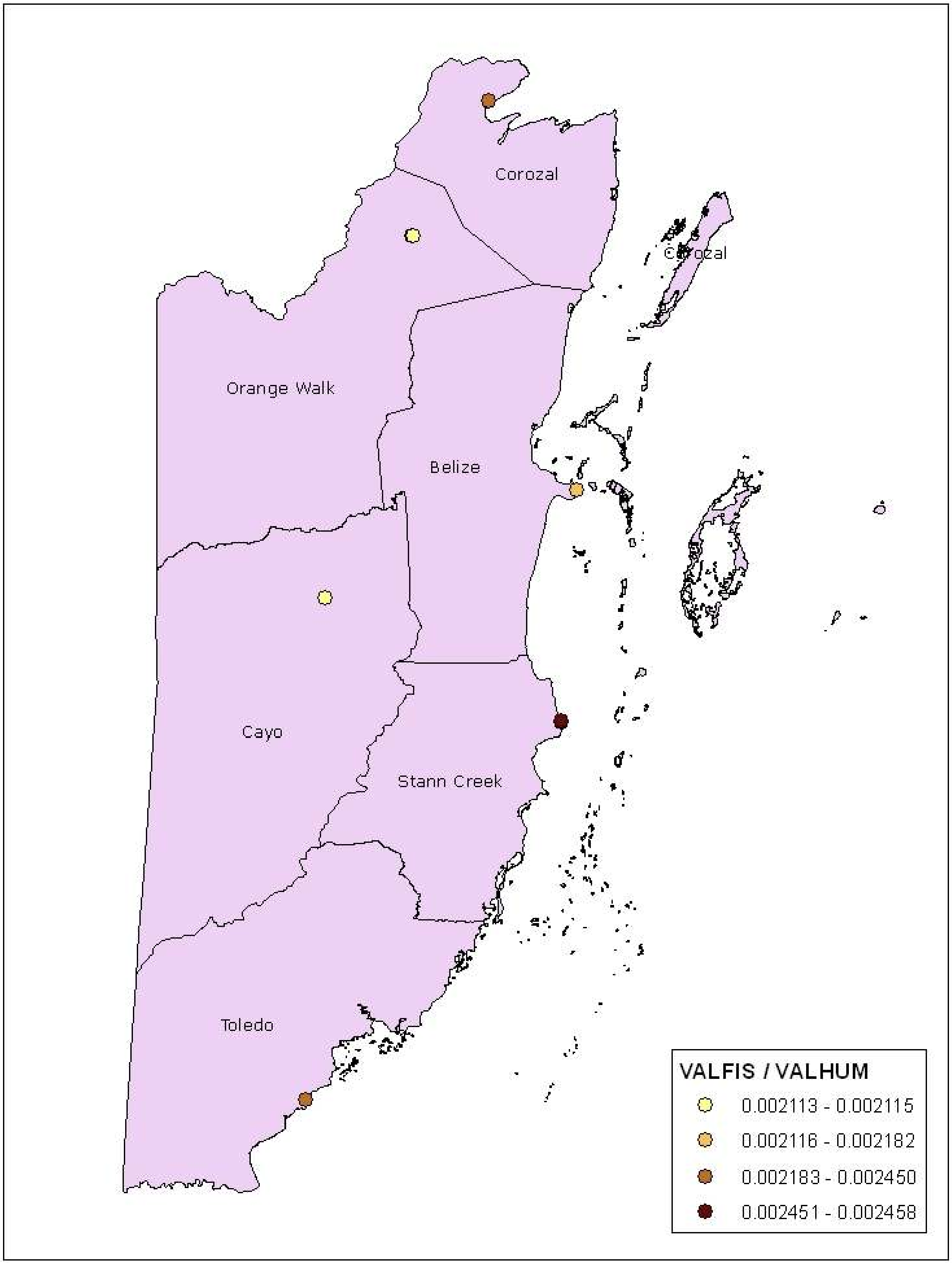

Figure 3-5 Belize. The geographical distribution of exposed elements

4 Vulnerability functions

4.1 Vulnerability for hurricane (wind)

For this analyisis, the building vulnerability is assigned following the procedure described below:

(a) Tipifiy the representative and dominant structural systems within the schools portfolio.
(b) Calculate the vulnerability functios for all characteristical construction classes. For this purpose different analytical models have been developed as well as previously published vulnerability functions were used according to previous experiences both at national and international level.
(c) Assignation of a characteristical construction class and a vulnerability function to each element within the exposed assets inventory.

A summary of the vulnerability functions used for the different exposed elements is shown below. Those vulnerability functions are based either on the equivalent behavior of typical components obtained from previous analysis or from specific analysis for design and construction conditions of the modeled elements.

4.2 Vulnerability functions for hurricane (wind)

The analysis considers the characteristics of typical structural systems, such as types of roof and facade, systems of frames, combined or dual systems, systems with structural walls, or prefabricated wood or concrete, etc. In general, the level of damage in those constructions depends on the type and quality of anchoring of roofs or prefabricated roofs and walls, and the quantity and size of doors and windows. Vulnerability functions of these kinds of buildings are graphically represented as a percentage of damage versus peak wind velocity.

The vulnerability functions are generated by using the ERN-vulnerability system (ERN, 2009), which forms part of the CAPRA platform for disaster risk analysis. These functions are generated in terms of peak wind speed at hurricane force. They are modified by factors which take into account particular aspects of the quality of local construction, the quality of materials, general conditions of the construction, construction practices and design, and specific characteristics of predominant types of structure. For each country, the main structural types were selected in accordance with the information available from the national census, in relation to construction materials, and characteristics of walls, floors and roofs. Furthermore, the information regarding to structural types provided by the World Housing Encyclopedia was also taken into account. Figure 4-1 presents the composition of constructed area by type of structure for each country. Figure 4-2 presents the functions of vulnerability allocated to constructions in this study.

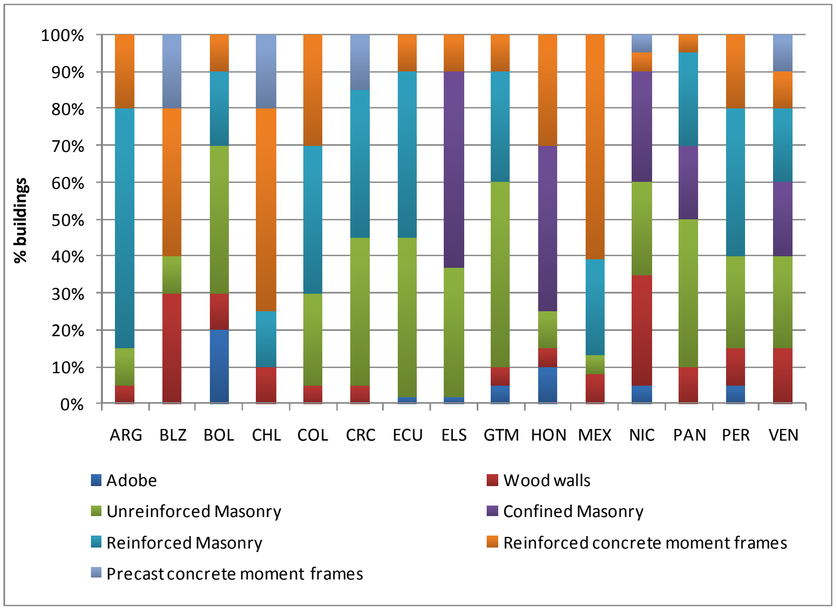

Figure 4-1
Composition of constructed area by types of structure in each country

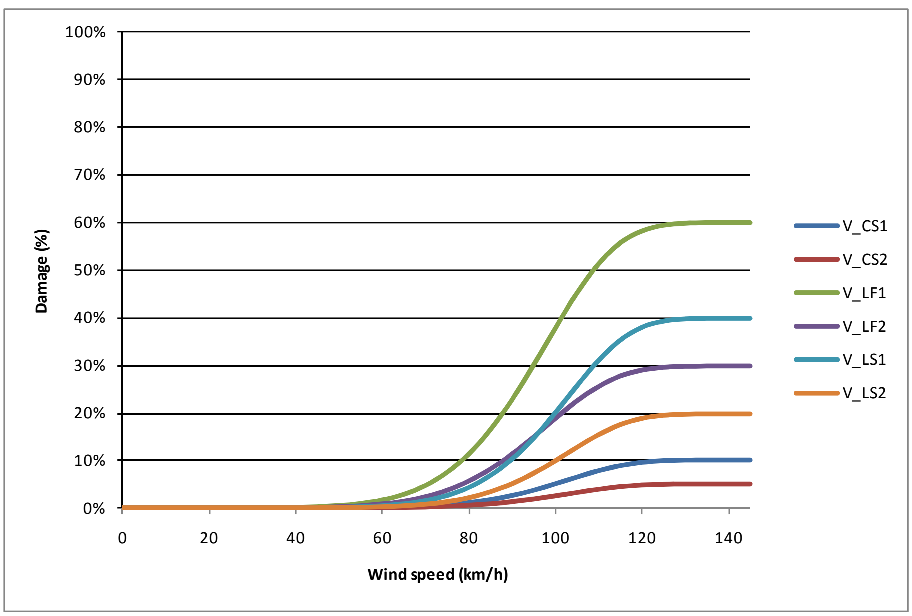

Figure 4-2
Vulnerability curves considered for the current portfolio of schools

4.3 Reinforcement costs

The costs of reinforcement are associated with structural interventions required to achieve a level of security defined for the building. This therefore depends on the structural system of the building and the current design code (seismic hazard, wind). For this study, the cost of reinforcement of schools is assumed as the standard cost for each type in all countries. These costs were related to available information on projects for risk reduction, mostly in relation to seismic risk, in schools in Latin America.

Two cases are available for this analysis, and they were used as a reference to estimate the cost of reinforcement. The first is a program to improve resistance to seismic vulnerability in schools in Quito, and the second a similar project for schools in Bogota. According to Coca (2006) the total investment in structural reinforcement and the improvement of schools in Bogota has been about US$162.7 million. The total area of buildings with structural intervention (reinforcement, replacement) was some 680,000 square meters, this includes 172 schools with structural reinforcement, 326 schools with non-structural improvements, and 54 extensions. Based on the study, the cost of structural intervention is the order of the order of US$240 per square meters .Examples of the schools concerned in this project are shown in Table 4-1.

Table 4-1
Examples of the results of seismic risk reduction in Bogota schools
Source: Bogota Education Office[1]

School	Results
Rodrigo Lara Bonilla	Capacity: 3,22 students; Constructed area 8,425 m^2 34 classrooms, 4 laboratories, 6 computer rooms, 1 library and 2 administrative areas.
Colegio San Carlos Sede B	Capacity: 1,280 students; Constructed area 2,767 m^2. 32 classrooms, 5 administrative areas, 4 laboratories, computer rooms, 4 bathrooms, 1 coliseum and one cafeteria.
Colegio Luis López de Mesa	Capacity: 2,000 students; Constructed area: 4,206 m^2. Retrofitting cost 3,800 million Colombian pesos (COP). 25 classrooms, 30 bathrooms, 6 administrative areas y 2 technology areas.
Colegio Alfonso López Pumarejo-Sede A	Capacity: 2,352 students, 28 classrooms, 1 technology room, 2 science rooms, 2 chemistry laboratories, 3 computer rooms and 1 administrative area.
Colegio distrital Marruecos y Molinos	38 classrooms, 4 laboratories, 4 administrative areas, 1 library and other facilities such as a nursery and parking lot.
Colegio Atanasio Girardot	Capacity: 2,240 students completely reconstructed. 24 classrooms, 3 laboratories, computer rooms, 3 administrative areas and many other facilities.

[1] http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=436

http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=417

http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=327

http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=224

Using the information available from experiences mentioned above, the cost of reinforcement was assumed for each construction material, as shown in Table 4-2.

Table 4-2
Cost of reinforcement considered in the analysis

Materials	Cost of reinforcement (US$/m^2)	
	Quake	Wind
Adobe	50	15
Wood	200	70
Simple masonry	250	80
Confined masonry	100	30
Reinforced masonry	200	70
Reinforced concrete frames	300	100
Precast reinforced concrete	300	100

5 Analysis results

The results of the analysis are now presented for the evaluation of risk due to hurricane winds in Belize schools in their current state and after structural reinforcement. The results presented in terms of probable maximum loss, for various return periods, and an average annual loss.

5.1 Actual state

Table 5-1
General results (Actual state)

Results		
Exposed value	US$ mill.	105.00
Average annual loss	US$ mill.	1.83
	‰	17.43‰
PML		
Return period	**Loss**	
years	**US$ mill.**	**%**
50	13.74	13.09%
100	16.96	16.15%
250	21.40	20.38%
500	23.97	22.82%
1,000	27.82	26.49%
1,500	28.57	27.21%

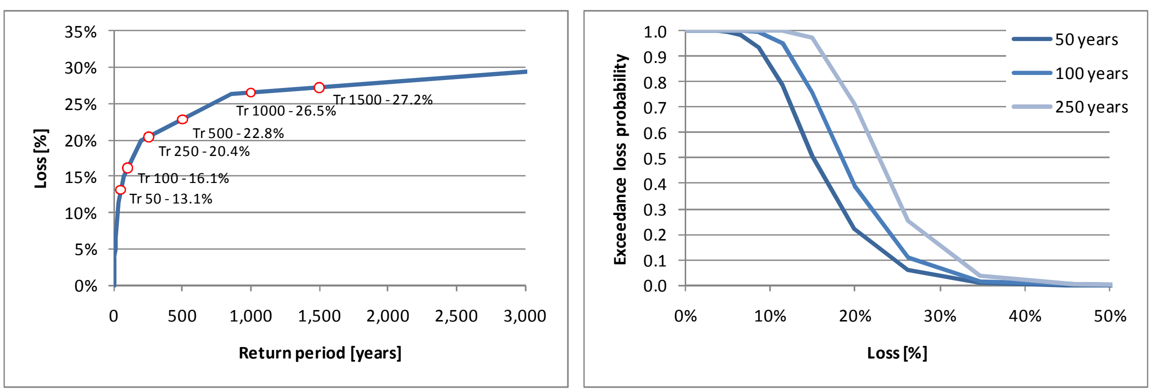

Figure 5-1
Analysis results
(Left: Probable maximum loss curve, Right: Exceedance loss probability for different exposition timeframes)

5.2 Retrofitted schools

Table 5-2
General results (Retrofitted schools)

Results		
Exposed value	US$ mill	105.00
Average annual loss	US$ mill	1.53
	‰	14.57‰
PML		
Return period	**Loss**	
years	**US$ mill**	**%**
50	12.80	12.19%
100	16.26	15.49%
250	21.00	20.00%
500	23.29	22.18%
1,000	27.64	26.33%
1,500	28.35	27.00%

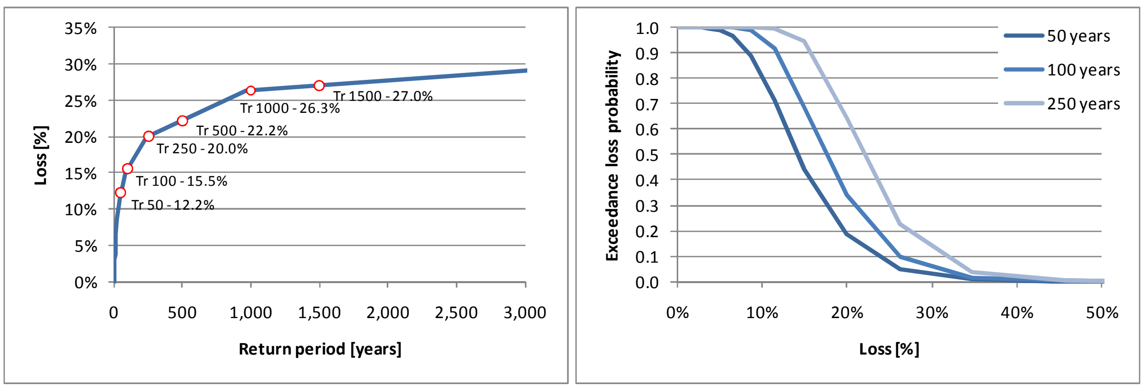

Figure 5-2
Analysis results
(Left: Probable maximum loss curve, Right: Exceedance loss probability for different exposition timeframes)

5.3 Benefit-cost ratio

The figures shown below present rates of exceedance of loss for the current condition of the schools and of the schools as reinforced. Additionally, Table 5-3 presents the results of the cost-benefit analysis

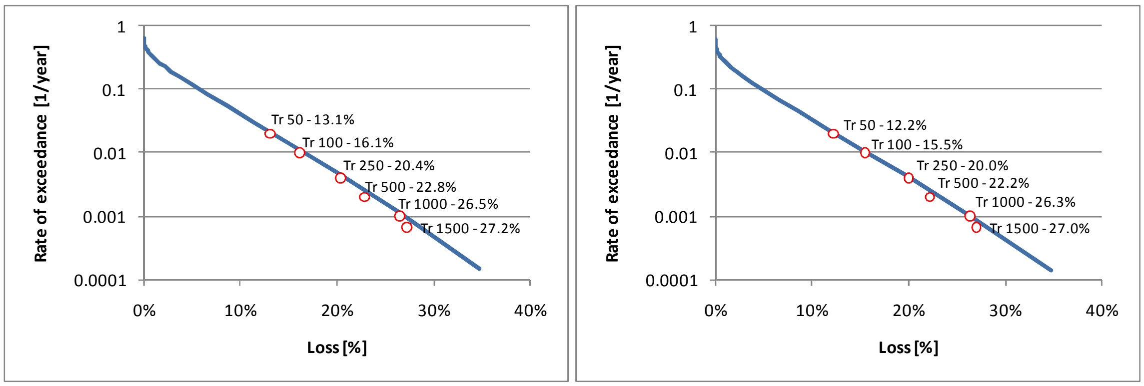

Figure 5-3
Analysis results
(Left: Loss exceedance curve in actual state, Right: Loss exceedance curve in reinforced state)

Table 5-3
Benefit-cost analysis results

State	E(L)	Var(L)
Actual (US$ mill.)	61.6	296.2
Retrofitted (US$ mill.)	51.6	243.7
Benefit-cost ratio		
R	13	
E(Q)	0.78	
Pr(Q>1)	99%	

From the analysis made for the portfolio of schools, the values obtained for the expected cost-benefit ratio, **E(Q)** of 0.78, and the probability that the ratio will be higher than 1 is 100%. This means that given the costs associated with reconditioning to take schools to an improved condition of security and safety, the probability of obtaining a benefit-cost ratio regarding to the events is high, simply from the economic point of view.

6 Conclusions and recommendations

The benefit-cost analysis requires the definition of a series of complementary elements, including the integral analysis of benefits, and the analysis of the ratio between the cost of reconditioning and the reduction in vulnerability.

For an integral analysis of the eventual benefits obtained by intervention or reconditioning of structure must consider the following expected losses, to include all components projected over time:

a) Direct:
   - Structure
   - Finishings
   - Contents
   - Human
b) Indirect:
   - Loss of income/interruption of operations
   - Maintenance costs
   - In the social costs
   - Environmental effects
   - Opportunity and development costs.

However, it should be noted that not all losses or impacts are to be measured in economic terms. For example, the loss of human life or indirect social impact, such as those associated with possible interruptions to the education service, are not easily quantifiable in these terms, and therefore they are in general not added in with the others, but treated as complementary.

Another important consideration for the cost benefit analysis refers to the establishment of appropriate functions between the costs of reconditioning and the reduction of vulnerability represented by the reduction in terms of expected losses for a given situation. This ratio is usually proposed at the level of a defined state, such as for example, what the cost would be of bringing a vulnerable structure to a level of safety compatible with current regulations, and thus defining the associated level for the reconditioned unit, and this corresponds to the level of safety established by regulations.

In most situations, the ratio between reconditioning and reduction of vulnerability depends on each of the buildings to be intervened, and it is therefore not easy to propose generalized models for such a relationship. It is recommended in general that specialists should be consulted to provide a balanced ratio, i.e. one which would correspond to realities.

Indicative models can be proposed, to allow preliminary analyses to be made, for example on the basis of the cost per square meter required to reduce vulnerability in percentage terms.

Then, depending on this relationship, a number of analyses can be made for different levels of security and safety (options in reconditioning), in order to obtain a final relationship between the cost of the initial investment and the related cost-benefit ratio.

The evaluation of the distribution of cost-benefit ratios in terms of probability is a good tool for decision-making, using the analysis of the net benefits of measures for risk mitigation, both in structural reconditioning work, the allocation of priorities for investments in reconditioning, decision-making regarding the renewal of assets, and proposals in construction and reinforcement codes. Given the stochastic nature of natural phenomena, in this analysis the net present value of losses is a quantity with a high level of uncertainty. Therefore, decisions should not be based solely on expected values; and therefore, methods must be used to provide a determination of the probability of having a positive cost-benefit ratio, and selecting the alternative with the highest probability.

7 References

Andreas J. Kappos and E.G. Dimitrakopoulos (2008) *Feasibility of pre-earthquake strengthening of buildings based on cost-benefit and life-cycle cost analysis, with the aid of fragility curves*. Natural Hazards Volume 45, Number 1 / abril de 2008

Beraldo, S.; Montolio, D.; Turati, G.; (2009) *Healthy, educated and wealthy: A primer on the impact of public and private welfare expenditures on economic growth*. Journal of Socio-Economics Volume 38, Issue 6, December 2009, Pages 946-956

Casciati F.; Dusi F.; Manzoni E. (2004) *Seismic risk mitigation for schools and hospitals: some recent italian experiences*. Proceedings of the third European Conference on Structural Control. 3ECSC. 12-15 July 2004. Vienna University of Technologie, Vienna, Austria.

CEPAL (2003). Manual para la evaluación del impacto socioeconómico y ambiental de los desastres.

CERF (2010) CERF around the World » Chile 2010 [On line]. Última actualización 19 de marzo de 2010. Available at: <http://ochaonline.un.org/CERFaroundtheWorld/Chile2010/tabid/6600/language/en-US/Default.aspx> [Last checked 12/04/2010]

Coca, C. (2006*) Risk management and sustainability in educative sector experience of Bogota, Colombia*. [On line]. Available at: <http://www.preventionweb.net/english/professional/trainings-events/edu-materials/v.php?id=7673> [Last checked 25/04/2010]

Dasgupta P.; Weale M. (1992) On measuring the quality of life. World Development 20(1): 119-131

ECLAC (2003) Handbook for Estimating the Socio-economic and Environmental Effects of Disasters. Economic Commission for Latin America and the Caribbean [On line] Available at: http://www.eclac.org/cgi-bin/getProd.asp?xml=/publicaciones/xml/4/12774/P12774.xml&xsl=/mexico/tpl-i/p9f.xsl&base=/mexico/tpl/top-bottom.xslt > [Last Checked 15/07/07]

EERI (2003) *Preliminary Observations on the October 31-November 1, 2002 Molise, Italy, Earthquake Sequence*. EERI Learning from Earthquakes. Special Earthquake Report — January 2003.[On line]. Available at: < http://www.eeri.org/lfe/pdf/italy_molise_eeri_report.pdf > [Last checked 06/04/2010]

EERI (2007) *The Pisco, Peru, Earthquake of August 15, 2007*. EERI Special Earthquake Report October 2007. Learning from Earthquakes [On line]. Available at: <http://www.eeri.org/lfe/pdf/peru_pisco_eeri_preliminary_reconnaissance.pdf> [Last checked 05/04/2010]

Ellul, F.; D'Ayala, D. (2003) *The Bingol, Turkey earthquake of the 1st of may 2003*. University of Bath. Architecture and civil engineering department. [On line]. Available at: < http://www.istructe.org/eefit/files/BingolFieldReport.pdf>

FEMA -Federal Emergency Management Agency (1992) *A benefit/cost model for the seismic rehabilitation of buildings* (FEMA 227), Vols 1, 2. VSP Associates, Sacramento, California

FEMA -Federal Emergency Management Agency (1994) *Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model Volume 2 - Supporting Documentation*. (FEMA-256 I) Sept 1994 Prepared for the Federal Emergency Management Agency Under Contract No. EMW-92-6-3976 by VSP Associates, Inc. 455 University Avenue, Suite 340 Sacramento, CA 95825 June 30, 1994

Ferreira M.A.; Proença J.M.; Oliveira C.S. (2008) *Vulnerability Assessment in Educational Buildings–Inference of Earthquake Risk. A Methodology Based on School Damage in the July 9, 1998, Faial Earthquake in the Azores*. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China. Paper 09-01-0014

Ferreira M. A.; Proença J.M. (2008) *Seismic Vulnerability Assessment of the Educational System of Bucharest*. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China. Paper ID 09-01-0110

Fierro, E.; Perry, C. (2010) *Preliminary Reconnaissance Report: 12 January 2010 Haiti Earthquake*. Reconnaissance and Report partially supported by: The Pacific Earthquake Engineering Research Center (PEER). [On line] Available at: http://peer.berkeley.edu/publications/haiti_2010/documents/Haiti_Reconnaissance.pdf [Last checked 04/03/2010]

Fujieda A.; Pandey B.; Ando, S. (2008) *Safe Schools to Reduce Vulnerability of Children to Earthquakes*. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China. Paper ID 09-01-0081

GeoHazards International, Escuela Politécnica Nacional (1995) *Invirtiendo en el futuro de Quito. Proyecto de Seguridad Sísmica de las edificaciones escolares de Quito, Ecuador*. [On line] Available at: http://www.geohaz.org/news/images/publications/QuitoSchoolProjectSpanish.pdf [Last checked 02/06/2010]

Lopez O.A.; Hernandez, J.J.; Marinilli A.; Bonilla R.; Fernandez N.; Dominguez J.; Baloa T.; Coronel G.; Safina S.(2008) *Seismic Evaluation and Retrofit of School Buildings in Venezuela*. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China. Paper ID 09-01-0041

Martinelli A.; Mannella A.; Milano L.; Cifani G.; Lemme A.; Miozzi C.; Mancini C. (2008) The Seismic Vulnerability of School Buildings in Molise (Italy): *The "Safe School Project", from Seismic Vulnerability Studies to an Intervention Classification*. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China. Paper ID 09-01-0086

Mora, M.G.; Ordaz, M.; Yamin, L.E.; Cardona, O.D.; (2009) *Relaciones beneficio costo probabilistas del refuerzo sísmico de edificios*. Memorias del IV Congreso Nacional de Ingeniería Sísmica. Pereira, Colombia mayo 13, 14 y 15 de 2009

OCHA (2008 c) *Situation Report 3 – Earthquake in Pakistan 31 Octubre 2008* [On line] Available at: <http://wwww.reliefweb.int/rw/RWFiles2008.nsf/FilesByRWDocUnidFilename/MUMA-7KY3GN-full_report.pdf/$File/full_report.pdf > [Last checked 12/04/2010]

OCHA (2009) Indonesia Earthquake Situation Report No. 14 Date: 13 October 2009 [On line]. Available at: < http://ocha-gwapps1.unog.ch/rw/rwb.nsf/db900sid/ACOS-64D3J8?OpenDocument> [Last checked 06/03/2010]

Reliefweb (2002) Afghanistan: Earthquake Appeal No.10/02. 12 abril 2002. [On line]. Available at: http://www.reliefweb.int/rw/RWFiles2009.nsf/FilesByRWDocUnidFilename/EDIS-7WSKEP-full_report.pdf/$File/full_report.pdf [Last checked 05/03/2010]

Secretaría de Educación de Bogotá (2004) *"REFORZAMIENTO ESTRUCTURAL SED.xls" [Libro de Excel]*

Secretaría de Educación de Bogotá (2008) *Plan Sectorial de Educación 2008-2012 Educación de Calidad para una Bogotá Positiva.* [On line]. Available at: <http://www.slideshare.net/colsaludcoopnorte/plan-sectorial-educacion-de-calidad-2008-2012> [Last checked 02/06/2010]

UNESCO (2010) *Reaching the marginalized*. EFA Global Monitoring Report. Education For All 2010. Oxford University Press. United Nations Educational, Scientific and Cultural Organization 7, Place de Fontenoy, 75352 Paris 07 SP, France

Ventura, C., Taylor, G., White, T., Finn, Liam., (2006) Bridging guidelines for the performance-based seismic retrofit of British Columbia low-rise school buildings. Second Edition . The British Columbia Ministry of Education. University of British Columbia. Association of Professional Engineers and Geoscientist of BC.